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V. *On the Absorption and Radiation of Heat by Gaseous and Liquid Matter*.—Fourth Memoir. By JOHN TYNDALL, F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution.

Received June 18,—Read June 18, 1863.

### § 1.

THE Royal Society has already done me the honour of publishing in the Philosophical Transactions three memoirs on the relations of radiant heat to the gaseous form of matter. In the first of these memoirs\* it was shown that for heat emanating from the blackened surface of a cube filled with boiling water, a class of bodies which had been previously regarded as equally, and indeed, as far as laboratory experiments went, perfectly diathermic, exhibited vast differences both as regards radiation and absorption. At the common tension of one atmosphere the absorptive energy of olefiant gas, for example, was found to be 290 times that of air, while when lower pressures were employed the ratio was still greater. The reciprocity of absorption and radiation on the part of gases was also experimentally established in this first investigation.

In the second inquiry† I employed a different and more powerful source of heat, my desire being to bring out with still greater decision the differences which revealed themselves in the first investigation. By carefully purifying the transparent elementary gases, and thus reducing the action upon radiant heat, the difference between them and the more strongly acting compound gases was greatly augmented. In this second inquiry, for example, olefiant gas at a pressure of one atmosphere was shown to possess 970 times the absorptive energy of atmospheric air, while it was shown to be probable that when pressures of  $\frac{1}{30}$ th of an atmosphere were compared, the absorption of olefiant gas was nearly 8000 times that of air. A column of ammoniacal gas, moreover, 3 feet long, was found sensibly impervious to the heat employed in the inquiry, while the vapours of many of the volatile liquids were proved to be still more opaque to radiant heat than even the most powerfully acting permanent gases. In this second investigation, the discovery of dynamic radiation and absorption is also announced and illustrated, and the action of odours and of ozone on radiant heat is made the subject of experiment.

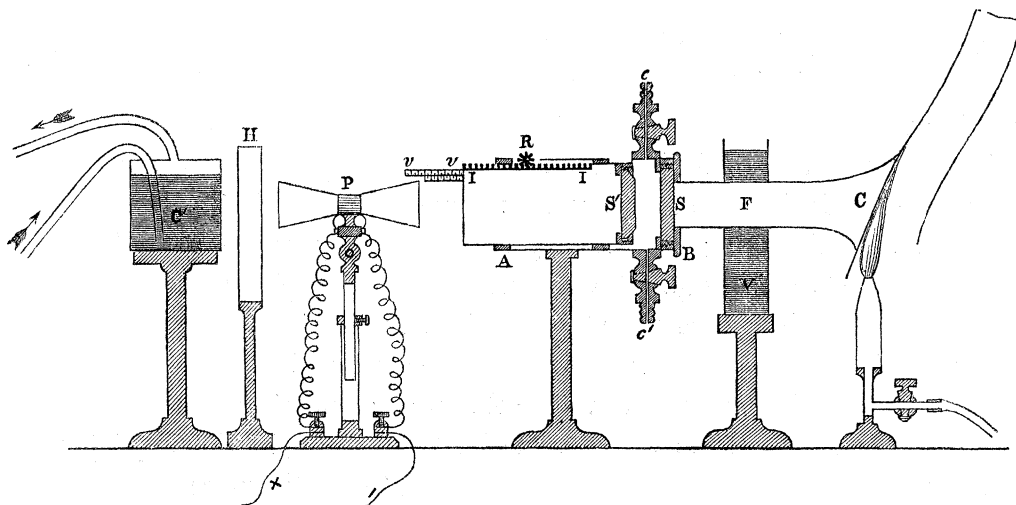
\* Philosophical Transactions, February 1861; and Philosophical Magazine, September 1861.

† Philosophical Transactions, January 1862; and Philosophical Magazine, October 1862.

The third paper\* of the series to which I have referred was devoted to the examination of one particular vapour, which on account of its universal diffusion possesses an interest of its own—I mean of course the vapour of water. In this paper I considered all the objections which had been urged against my results up to the time when the paper was written; I replied to each of them by definite experiments, removing them one by one, and finally placing, as I believe, beyond the pale of reasonable doubt the action of the aqueous vapour of our atmosphere. In this third paper, moreover, the facts established by experiment are applied to the explanation of various atmospheric phenomena.

I have now the honour to lay before the Royal Society a fourth memoir, containing an account of further researches. Hitherto I have confined myself to experiments on radiation through gases and vapours which were introduced in succession into the same experimental tube, the heat being thus permitted to pass through the same thickness of different gases. A portion of the present inquiry is devoted to the examination of the transmission of radiant heat through different thicknesses of the same gaseous body. The brass tube with which my former experiments were conducted is composed of several pieces, which are screwed together when the tube is to be used as a whole; but the pieces may be dismantled and used separately, a series of lengths being thus attainable, varying from 2·8 inches to 49·4 inches. I wished, however, to operate upon gaseous strata much thinner than the thinnest of these, and for this purpose a special apparatus was devised, and with much time and trouble rendered at length practically effective.

Fig. 1.



The apparatus is sketched in fig. 1. C is the source of heat, which consists of a plate of copper against the back of which a steady sheet of flame is caused to play. The plate of copper forms one end of the chamber F (the “front chamber” of my former memoirs). This chamber, as in my previous investigations, passes through the vessel

\* Philosophical Transactions, December 1862; and Philosophical Magazine, July 1863.

V, through which cold water continually circulates, entering at the bottom and escaping at the top. The heat is thus prevented from passing by conduction from the source C to the first plate of rock-salt S. This plate forms the end of the hollow cylinder A B, dividing it from the front chamber F, with which the cylinder A B is connected by suitable screws and washers. Within the cylinder A B moves a second one, I I, as an air-tight piston, and the bottom of the second cylinder is stopped by the plate of rock-salt S'. This plate projects a little beyond the end of its cylinder, and thus can be brought into flat contact with the plate S. Fixed firmly to A B is a graduated strip of brass, while fixed to the piston is a second strip, the two strips forming a vernier, *vv*. By means of the pinion R, which works in a rack, the two plates of salt may be separated, their exact distance apart being given by the vernier. P is the thermo-electric pile with its two conical reflectors; C' is the compensating cube, employed to neutralize the radiation from the source C. H is an adjusting screen, by the motion of which the neutralization may be rendered perfect, and the needle brought to zero under the influence of the two opposing radiations. The graduation of the vernier was so arranged as to permit of the employment of plates of gas varying from 0.01 to 2.8 inches in thickness. They were afterwards continued with the pieces of the experimental tube, already referred to, and in this way layers of gas were examined which varied in thickness in the ratio of 1 : 4900.

In my former experiments the chamber F was always kept exhausted, so that the rays of heat passed immediately from the source through a vacuum; but in the present instance I feared the strain upon the plate S, and I also feared the possible intrusion of a small quantity of the gas under examination into the front chamber F, if the latter were kept exhausted. Having established the fact that a length of 8 inches of dry air exerts no sensible action on the rays of heat, I had no scruple in filling the chamber F with dry air. Its absorption was *nil*, and it merely had the effect of lowering in an infinitesimal degree the temperature of the source. The two stopcocks *c* and *c'* stand exactly opposite the junction of the two plates of salt S, S' when they are in contact, and when they are drawn apart these cocks are in communication with the space between the plates.

After many trials, the following mode of experiment was adopted:—The gas-holder containing the gas to be examined was connected by an india-rubber tube with the cock *c'*, the other cock *c* being at the same time left open. The piston was then moved by the screw R until the requisite distance between the plates was obtained. This space being filled with dry air, the radiations on the two faces of the pile were equalized, and the needle brought to zero. The gas-holder was now opened, and by gentle pressure the gas from the holder was forced first through a drying apparatus, and then into the space between the plates of salt. The air was quickly displaced, and a plate of the gas substituted for it. If the layer of gas possessed any sensible absorbing power, the equilibrium of the two sources of heat would be destroyed; the source C' would triumph, and from the deflection due to its preponderance the exact amount of heat intercepted by the gas could be calculated.

When oxygen, hydrogen, or nitrogen was substituted for atmospheric air, no change in the position of the galvanometer-needle occurred; but when any one of the compound gases was allowed to occupy the space between the plates, a measurable deflection ensued. The plates of rock-salt were not so smooth, nor was their parallelism so perfect as entirely to exclude the gas when they were in contact. The contact was but partial, and hence a stratum of gas sufficient to effect a sensible absorption could find its way between the plates even when they touched each other. On this account the first thickness in the following Tables was really a little more than 0·01 of an inch. The first column in each contains the thickness of the gaseous layer, while the second column contains the absorption expressed in hundredths of the total radiation. The first layer of carbonic oxide, for example, absorbed 0·2, and the second layer 0·5 per cent. of the entire heat.

TABLE I.—Carbonic Oxide.

Thickness of gas.	Absorption in hundredths of the total radiation.	Thickness of gas.	Absorption in hundredths of the total radiation.
0·01 of an inch	0·2	0·4 of an inch	3·5
0·02 „	0·5	0·5 „	3·8
0·03 „	0·7	0·6 „	4·0
0·04 „	0·9	1·0 „	5·1
0·06 „	1·4	1·5 „	6·1
0·1 „	1·6	2·0 „	6·8
0·3 „	3·0		

TABLE II.—Carbonic Acid.

Thickness of gas.	Absorption in hundredths of the total radiation.	Thickness of gas.	Absorption in hundredths of the total radiation.
0·01 of an inch	0·86	0·4 of an inch	5·3
0·02 „	1·2	0·5 „	5·7
0·03 „	1·5	0·6 „	5·9
0·04 „	1·9	0·7 „	6·0
0·05 „	2·1	0·8 „	6·1
0·06 „	2·3	0·9 „	6·2
0·1 „	3·3	1·0 „	6·3
0·2 „	4·1	1·5 „	7·0
0·3 „	4·8	2·0 „	7·6

TABLE III.—Nitrous Oxide.

Thickness of gas.	Absorption in hundredths of the total radiation.	Thickness of gas.	Absorption in hundredths of the total radiation.
0·01 of an inch . . .	1·48	0·4 of an inch . . .	10·20
0·02 „ . . .	2·33	0·5 „ . . .	11·00
0·03 „ . . .	3·80	0·6 „ . . .	11·70
0·04 „ . . .	4·00	0·8 „ . . .	12·17
0·05 „ . . .	4·20	1·0 „ . . .	12·80
0·1 „ . . .	6·00	1·5 „ . . .	14·20
0·2 „ . . .	7·77	2·0 „ . . .	15·7

TABLE IV.—Olefiant Gas.

Thickness of gas.	Absorption in hundredths of the total radiation.	Thickness of gas.	Absorption in hundredths of the total radiation.
0·01 of an inch . . .	1·80	0·5 of an inch . . .	23·30
0·02 „ . . .	3·08	1·0 „ . . .	26·33
0·05 „ . . .	5·37	2·0 „ . . .	32·80
0·1 „ . . .	9·14		

We here find that a layer of olefiant gas only 2 inches in thickness intercepts nearly 33 per cent. of the radiation from our source. Supposing our globe to be encircled by a shell of olefiant gas only 2 inches in thickness, this shell would offer a scarcely sensible obstacle to the passage of the solar rays earthward, but it would cut off at least 33 per cent. of the terrestrial radiation and in great part return it. Under such a canopy, trifling as it may appear, the surface of the earth would be kept at a stifling temperature. The possible influence of an atmospheric envelope on the temperature of a planet is here forcibly illustrated.

The only *vapour* which I have examined with the piston apparatus is that of sulphuric ether. Glass fragments were placed in a U-tube and wetted with the ether. Through this tube dry air was gently forced, whence it passed, vapour-laden, into the space between the rock-salt plates S S'. The following Table contains the results.

TABLE V.—Air saturated with the Vapour of Sulphuric Ether.

Thickness of vapour.	Absorption in hundredths of the total radiation.	Thickness of vapour.	Absorption in hundredths of the total radiation.
0·05 of an inch . . .	2·07	0·8 of an inch . . .	21·0
0·1 „ . . .	4·6	1·5 „ . . .	34·6
0·2 „ . . .	8·7	2·0 „ . . .	35·1
0·4 „ . . .	14·3		

Comparing these results with those obtained with olefiant gas, we find for thicknesses of 0·05 of an inch and 2 inches respectively the following absorptions:—

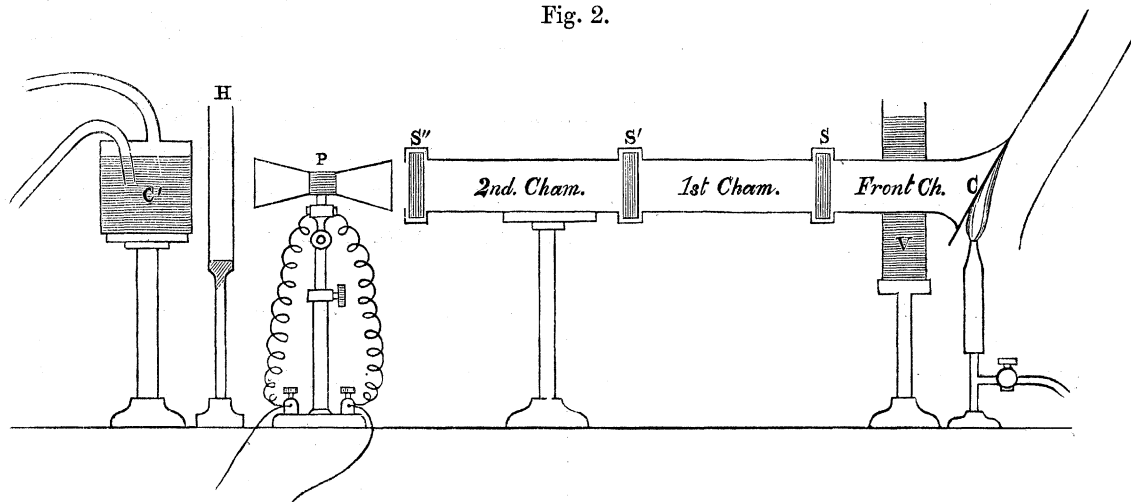
Olefiant gas.		Sulphuric ether.	
Thickness of 0·05 . . .	5·37	Thickness of 0·05 . . .	2·07
Thickness of 2 inches . .	32·80	Thickness of 2 inches . .	35·1

Sulphuric ether vapour, therefore, commences with an absorption much lower than that of olefiant gas, and ends with a higher absorption. This is quite in accordance with the result established in my second memoir\*, that in a short tube the absorption effected by the sparsely scattered molecules of a vapour may be less than that of a gas at a tension of an atmosphere, while in a long tube the gas may be exceeded by the vapour. The deportment of sulphuric ether indicates what mighty changes of climate might be brought about by the introduction into the earth's atmosphere of an almost infinitesimal amount of a powerful vapour. And if *aqueous vapour* can be shown to be thus powerful, the effect of its withdrawal from our atmosphere may be inferred.

## § 2.

The experiments with the piston apparatus being completed, greater thicknesses of gas were obtained by means of the composite brass experimental tube already referred to. The arrangement adopted was, however, peculiar, being expressly intended to check the experiments, which were for the most part made by my assistants. The source of heat and the front chamber remained as usual; a plate of rock-salt dividing, as in my previous investigations, the front chamber from the experimental tube. The distant end of the tube was also stopped by a plate of salt; but instead of permitting the tube to remain continuous from beginning to end, it was divided, by a third plate of rock-salt,

Fig. 2.



into two air-tight compartments. Thus the rays of heat from the source had to pass through *three* distinct chambers, and through three plates of salt. The first chamber

\* Philosophical Transactions, Part I. 1862; and Philosophical Magazine, vol. xxiv. p. 343.

was always kept filled with perfectly dry air, while either or both of the other chambers could be filled at pleasure with the gas or vapour to be examined. For the sake of convenience I will call the compartment of the tube nearest to the front chamber the *first* chamber, the compartment nearest to the pile the *second* chamber; the term 'front chamber' being, as before, restricted to that nearest to the source. The arrangement is sketched in outline in fig. 2.

The entire length of the tube was 49·4 inches, and this was maintained throughout the whole of the experiments. The only change consisted in the shifting of the plate of salt S' which formed the partition between the first and second chambers. Commencing with a first chamber of 2·8 inches long, and a second chamber 46·4 inches long, the former was gradually augmented, and the latter equally diminished. The experiments were executed in the following manner:—The first and second chambers were thoroughly cleansed and exhausted, and the needle brought to zero by the equalization of the radiations falling upon the opposite faces of the pile. Into the first chamber the gas or vapour to be examined was introduced, and its absorption determined. The first chamber was then cleansed, and the gas or vapour was introduced into the second chamber, its absorption there being also determined. Finally, the absorption exerted by the two chambers acting together was determined, both of them being occupied by the gas or vapour.

The combination here described enabled me to check the experiments, and also to trace the influence of the first chamber on the quality of the radiation. In it the heat was more or less sifted, and it entered the second chamber deprived of certain constituents which it possessed on its entrance into the first. On this account the quantity absorbed in the second chamber when the first chamber is full of gas, must always be less than it would be if the rays had entered without first traversing the gas of the first chamber. From this it follows that the sum of the absorptions of the two chambers, taken separately, must always exceed the absorption of the tube taken as a whole. This may be briefly and conveniently expressed by saying that the sum of the absorptions exceeds the absorption of the sum.

TABLE VI.—Carbonic Oxide.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	6·8	12·9	12·9
8·0	41·4	9·6	12·2	12·9
12·2	37·2	10·7	12·2	12·9
15·4	34·0	10·9	12·2	13·4
17·8	31·6	11·1	12·0	13·3
36·3	13·1	12·6	10·3	13·4



TABLE VII.—Carbonic Acid.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	8·6	13·8	13·3
8·0	41·4	9·9	12·7	13·0
12·2	37·2	11·0	11·4	13·0
15·4	34·0	11·8	12·1	13·9
23·8	25·6	11·7	11·4	13·1
23·8	25·6	11·2	11·2	12·6
23·8	25·6	10·4	10·5	12·0
36·3	13·1	11·6	10·0	12·3

Various causes have rendered these experiments exceedingly laborious. Could I have procured a sufficiently large quantity of gas in a single holder for an entire series of experiments it would not have been difficult to obtain concurrent results, but the slight variations in quality of the same gas generated at different times tell upon the results and render perfect uniformity extremely difficult to obtain. The approximate constancy of the numbers in the third column is, however, a guarantee that the determinations are not very wide of the truth. Irregularities, however, are revealed. Some remarkable ones occur in the case of carbonic acid, with the chambers 23·8 and 25·6; the absorptions in the first chamber varying in this instance from 11·7 to 10·4, and in the second chamber from 11·4 to 10·5, and in both chambers from 13·1 to 12·0. The gas which gave the largest of these results was generated from marble and hydrochloric acid; the next was obtained from chalk and sulphuric acid, and the gas which gave the smallest result was obtained from bicarbonate of soda and sulphuric acid. The slight differences accompanying these different modes of generation made themselves felt in the manner recorded in the Table.

TABLE VIII.—Nitrous Oxide.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	16·1	32·9	33·9
12·2	37·2	23·1	30·0	32·0
15·4	34·0	23·6	29·6	32·0
17·8	31·6	26·2	29·6	32·7

The differences arising from different modes of generation are most strikingly illustrated by the powerful gases. My friend Dr. FRANKLAND, for example, was kind enough to superintend for me the formation of a large holder of olefiant gas by the so-called "continuous process," in which the *vapour* of alcohol is led through sulphuric acid diluted with its own volume of water; the following results were obtained:—

TABLE IX.—Olefiant Gas.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	34·6	66·1	67·7
8·0	41·4	44·2	65·3	67·5
15·4	34·0	53·6	62·3	67·0

Considering the difficulty of the experiments, the agreement of the absorption of both chambers, the sum of which was the constant quantity 49·4 inches, must be regarded as satisfactory. This is the general character of the results as long as we adhere to the same gas. Olefiant gas generated by mixing the *liquid* alcohol with sulphuric acid and applying heat to the mixture, gave the results recorded in the following Table:—

TABLE X.—Olefiant Gas.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
12·2	37·2	54·8	70·0	76·3
15·4	34·0	59·1	72·7	77·1
19·8	29·6	67·8	70·4	77·0
23·8	25·6	69·2	70·2	77·6
36·3	13·1	72·8	60·3	78·8

The absorptions of both chambers in this Table are almost exactly 10 per cent. higher than those found with the gas generated under Dr. FRANKLAND'S superintendence.

A few remarks on these results may be introduced here. In the case of carbonic oxide (Table VI.), we see that while a length of 2·8 inches of gas is competent, when acting alone, to intercept 6·8 per cent. of the radiant heat, the cutting off of this length from a tube 49·4 inches long, or, what is the same, the addition of this length to a tube 46·6 inches long, makes no sensible change in its absorption. The second chamber absorbs as much as both. The same remark applies to carbonic acid, and it is also true within the limits of error for nitrous oxide and olefiant gas. Indeed it is only when 8 inches or more of the column have been cut away that the difference begins to make itself felt. Thus, in carbonic oxide, the absorption of a length of 41·4 being 12·2, that of a chamber 49·4, or 8 inches longer, is only 12·9, making a difference of only 0·7 per cent., while the same 8 inches acting singly on the gas produces an absorption of 9·6 per cent. So also with regard to carbonic acid; a tube 41·4 absorbing 12·7 per cent., a tube 49·4 absorbs only 13·0 per cent.—making a difference of only 0·3 per cent. As regards olefiant gas (Table IX.), while a distance of 8 inches acting singly effects an absorption of 44 per cent., the addition of 8 inches to a tube already 41·4 inches in length raises the absorption only from 65·3 to 67·5, or 2·2 per cent. The reason is plain. In a length of 41·4 the rays capable of being absorbed by the gas are so much diminished, so few in fact remain to be attacked, that an additional 8 inches of gas produces a scarcely sensible effect. Similar considerations explain the fact, that while by augmenting the length of

the first chamber from 2·8 inches to 15·4 inches we increase the absorption of olefiant gas nearly 20 per cent., the shortening of the second chamber by precisely the same amount effects a diminution of barely 4 per cent. of the absorption. All these results conspire to prove the heterogeneous character of the radiation from a source heated to about 250° C.

The sum of the absorptions placed side by side with the absorption of the sum exhibits the influence of sifting in an instructive manner. Tables VI., VII., VIII., IX., and X., thus treated, give the following comparative numbers:—

TABLE XI.—Carbonic Oxide.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	19·7	12·9
8·0	41·1	21·8	12·9
12·2	37·2	22·9	12·9
15·4	34·0	23·1	13·4
17·8	31·6	23·1	13·3
36·3	13·1	22·9	13·4
Means		22·3	13·1

TABLE XII.—Carbonic Acid.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	22·4	13·3
8·0	41·4	22·6	13·0
12·2	37·2	22·4	13·0
15·4	34·0	23·9	13·9
23·8	25·6	23·1	13·1
36·3	13·1	21·6	12·3
Means		22·6	13·1

TABLE XIII.—Nitrous Oxide.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	49·0	33·9
12·2	37·2	53·1	32·0
15·4	34·0	53·2	32·0
17·8	31·6	55·8	32·7
Means		52·8	32·7

TABLE XIV.—Olefiant Gas.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	100·7	67·7
8·0	41·4	109·5	67·5
12·2	37·2	109·4	65·0
15·4	34·0	115·9	67·0
Means		108·9	66·8

TABLE XV.—Olefiant Gas.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
12·2	37·2	124·8	76·3
15·4	34·0	131·8	77·1
19·8	29·6	138·2	77·0
23·8	25·6	139·4	77·6
36·3	13·1	133·1	78·8
Means		133·4	77·3

The conclusion that the sum of the absorptions is greater than the absorption of the sum is here amply verified. The Tables also show that the ratio of the sum of the absorptions to the absorption of the sum is practically constant for all the gases. Dividing the first mean by the second in the respective cases, we have the following quotients:—

Carbonic oxide . . . . .	1·70
Carbonic acid . . . . .	1·72
Nitrous oxide . . . . .	1·61
Olefiant gas (mean of both) . . . . .	1·68

The sum of the absorptions ought to be a maximum when the two chambers are of equal length. Supposing them to be unequal, one being in excess of half the length of the tube, let us consider the action of this excess singly. Placed after the half-length, it receives the rays which have already traversed that half; placed after the shorter length, it receives the rays which have traversed the shorter length. In the former case, therefore, the excess will absorb less than in the latter, because the rays in the former case have been more thoroughly sifted before the heat reaches the excess. From this it is clear that, as regards absorption, more is gained by attaching the excess to the short length of the tube than to the half-length; in other words, the sum of the absorptions, when the tube is divided into two equal parts, is a maximum. This reasoning is approximately verified by the experiments. Supposing, moreover, one of the lengths constantly to diminish, we thus constantly approach the limit when the sum of the absorptions and the absorption of the sum are equal to each other, the former being then a minimum. The effect of proximity to this limit is exhibited in the first experiment in each of the series; here the lengths of the compartments are very unequal, and the sum of the absorptions is, in general, a minimum.

After the absorption by the permanent gases had been in this way examined, I passed on to the examination of vapours. They were all used at a common pressure of 0·5 of an inch of mercury, or about  $\frac{1}{60}$ th of an atmosphere. The liquid which yielded the vapour was enclosed in the flasks described in my previous memoirs, and the pure vapour was allowed to enter the respective compartments of the experimental tube without the slightest ebullition. The following series of Tables contains the results thus obtained.

TABLE XVI.—Bisulphide of Carbon. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	3·6	7·6	7·6
8·0	41·4	4·4	7·3	7·6
15·4	34·0	5·7	6·0	7·5
17·8	31·6	5·8	6·4	7·5
23·8	25·6	6·7	6·0	7·8

TABLE XVII.—Chloroform. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	5·5	15·9	16·3
8·0	41·4	9·2	15·6	16·8
12·2	37·2	10·5	14·8	17·1
15·4	34·0	11·6	14·1	16·9
23·8	25·6	15·0	14·0	18·4
36·3	13·1	15·6	10·9	17·2

TABLE XVIII.—Benzol. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	4·0	20·0	20·6
8·0	41·4	8·4	17·3	20·4
12·2	37·2	9·8	16·5	19·0
17·8	31·6	11·9	15·7	20·1
23·8	25·6	14·3	15·1	21·0

TABLE XIX.—Iodide of Ethyl. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	7·1	23·5	25·4
8·0	41·4	9·1	21·1	23·3
12·2	37·2	12·8	20·5	25·2
15·4	34·0	14·6	20·8	25·2
17·8	31·6	15·8	20·0	25·5

TABLE XX.—Alcohol. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	11·7	46·1	46·1
8·0	41·4	18·5	43·6	47·0
12·2	37·2	26·0	44·1	47·5
15·4	34·0	32·1	41·1	47·0
17·8	31·6	32·4	40·0	47·6

TABLE XXI.—Alcohol. Pressure 0·1 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
8·0	41·4	8·0	22·2	24·9
15·4	34·0	12·1	20·0	24·7
17·8	31·6	13·1	19·7	25·7
23·8	25·6	14·8	18·4	25·2
36·3	13·1	19·1	13·8	25·1

TABLE XXII.—Sulphuric Ether. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	14·8	50·0	51·6
8·0	41·4	23·9	51·0	53·9
12·2	37·2	30·9	48·8	53·6
15·4	34·0	34·0	47·8	53·1

TABLE XXIII.—Acetic Ether. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	17·0	60·2	62·9
8·0	41·4	30·7	58·1	64·6
12·2	37·2	41·6	55·1	64·2
15·4	34·0	44·4	55·5	62·4
23·8	25·6	50·9	52·7	64·7
36·3	13·1	58·1	42·6	64·8

TABLE XXIV.—Formic Ether. Pressure 0·5 of an inch.

Length.		Absorption per 100.		
1st Chamber.	2nd Chamber.	1st Chamber.	2nd Chamber.	Both Chambers.
2·8	46·6	17·4	63·0	64·4
8·0	41·4	33·3	59·1	63·4
17·8	31·6	40·0	48·4	60·3
23·8	25·6	45·6	47·2	60·2

I have already compared the sum of the absorptions for gases with the absorption of the sum ; in the following Tables the same comparison is made for the vapours.

TABLE XXV.—Bisulphide of Carbon, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	11·2	7·6
8·0	41·4	11·7	7·6
15·4	34·0	11·7	7·5
17·8	31·6	12·2	7·5
23·8	25·6	12·7	7·8
		<hr/>	<hr/>
Means		11·9	7·6

TABLE XXVI.—Chloroform, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	21·4	16·3
8·0	41·4	24·8	16·8
12·2	37·2	25·3	17·1
15·4	34·0	25·2	16·9
23·8	25·6	29·0	18·4
36·3	13·1	26·5	17·2
		<hr/>	<hr/>
Means		25·36	17·1

TABLE XXVII.—Benzol, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	24·0	20·6
8·0	41·4	25·7	20·4
12·2	37·2	26·3	19·0
17·8	31·6	27·6	20·1
23·8	25·6	29·4	21·0
		<hr/>	<hr/>
Means		26·6	20·2

TABLE XXVIII.—Iodide of Ethyl, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	30·6	25·4
8·0	41·4	30·2	23·3
12·2	37·2	33·3	25·2
15·4	34·0	35·4	25·2
17·8	31·6	35·8	25·2
		<hr/>	<hr/>
Means		33·1	24·9

TABLE XXIX.—Alcohol, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	57·8	46·1
8·0	41·4	62·1	47·0
12·2	37·2	70·1	47·5
15·4	34·0	73·2	47·0
17·8	31·6	72·4	47·6
Means		67·1	47·0

TABLE XXX.—Alcohol, 0·1 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
8·0	41·4	30·2	24·9
15·4	34·0	32·1	24·7
17·8	31·6	32·8	25·7
23·8	25·6	33·2	25·2
36·3	13·1	32·9	25·1
Means		32·2	25·1

TABLE XXXI.—Sulphuric Ether, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	64·8	51·6
8·0	41·4	74·9	53·9
12·2	37·2	79·7	53·6
15·4	34·0	81·8	53·1
Means		75·3	53·05

TABLE XXXII.—Formic Ether, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	80·4	64·4
8·0	41·4	82·4	63·4
17·8	31·6	88·4	60·3
23·8	25·6	92·8	60·2
Means		86·0	62·07



TABLE XXXIII.—Acetic Ether, 0·5 inch.

Length of Chambers.		Sum of Absorptions.	Absorption of Sum.
2·8	46·6	77·2	62·9
8·0	41·4	88·8	64·6
12·2	37·2	96·7	64·2
15·4	34·0	99·9	62·4
23·8	25·6	103·6	64·7
36·3	13·1	100·7	64·8
Means		94·5	63·9

An inspection of the foregoing Tables discloses the fact that, in the case of vapours, the difference between the sum of the absorptions and the absorption of the sum is, in general, less than in the case of gases. This resolves itself into the proposition that for equal lengths, within the limits of these experiments, the sifting power of the gas is greater than that of the vapour. The reason of this is that the vapours are examined in a state of tenuity which is only  $\frac{1}{60}$ th of that possessed by the gases. Thus, no matter how powerful the individual molecules may be, their distance asunder renders a thin layer of them a comparatively open screen.

### § 3.

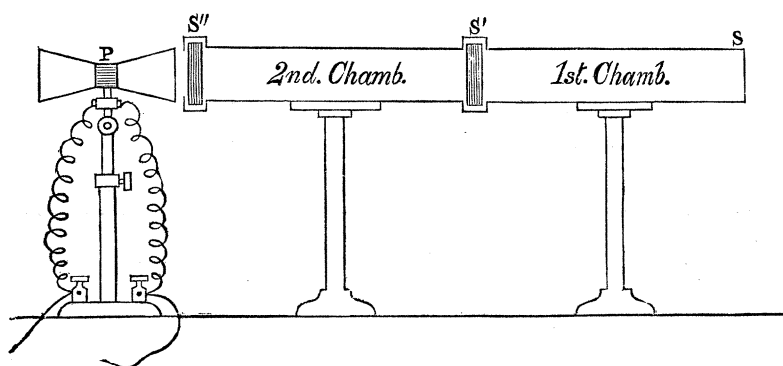
The entrance of a gas into an exhausted vessel is accompanied by the generation of heat; and the gas thus warmed, if a radiator, will emit the heat generated. Conversely, on exhausting a vessel containing any gas, the gas is chilled, and thus an external body, which prior to the act of exhaustion possessed the same temperature as the gas within the vessel, becomes, on the first stroke of the pump, a warm body with reference to the gas remaining in the vessel; and if the external body be separated from the cooled gas by a diathermic partition, it will radiate into the gas and become chilled by this radiation. It was shown in my second memoir\* that this mode of warming and of chilling a gas or vapour furnished a practical means of determining, without any source of heat external to the gaseous body itself, both its radiative and absorptive energy. For the sake of convenience I have called the radiation and absorption of a gas or vapour thus dynamically heated and cooled, dynamic radiation and dynamic absorption.

In illustration of the manner in which dynamic radiation may be applied in researches on radiant heat, I have had made, during the last half-year, a considerable number of experiments, some of which I will here describe. In the first place, the experimental tube was divided into two compartments, as in the experiments described in the foregoing section. The source of heat was abolished, and one end of the experimental tube was stopped by a plate of polished metal; the other end was stopped by a transparent plate of rock-salt, while the space between the ends was divided into two compartments

\* Philosophical Transactions, Part I. 1862; and Philosophical Magazine, vol. xxiv. p. 337.

by a second plate of rock-salt. The thermo-electric pile occupied its usual position at the end of the tube, the compensating cube, however, being abandoned. For the sake of convenient reference, I will call the compartment of the tube most distant from the pile, the first chamber, and that adjacent to the pile, the second chamber. An outline sketch of the arrangement is given in fig. 3.

Fig. 3.



The experiments were conducted in the following manner:—Both compartments being exhausted and the needle at zero, the gas was allowed to enter the first chamber through a gauge-cock which made its time of entry 40 seconds. The second chamber was preserved a vacuum; the gas on entering the first chamber was dynamically heated, and radiated its heat to the pile through the vacuous second chamber; the needle moved and the limit of its excursion was noted. The first chamber was then exhausted and carefully cleansed with dry air. The second chamber was filled with the same gas, not with a view to determine its dynamic radiation, but to examine its effect upon the heat radiated from the first chamber. The needle being at zero, the gas was again permitted to enter the first chamber exactly as in the first experiment, the only difference between the two experiments being, that in the first the heat passed through a vacuum to the pile, while in the second it had to pass through a column of the same kind of gas as that from which it emanated. In this way the absorption exerted by any gas upon heat, radiated from the same gas, or from any other gas, may be accurately determined. Finally, the apparatus being cleansed and the needle at zero, the gas was permitted to enter the second chamber, and its dynamic radiation from this chamber was determined. The intermediate plate of salt *S'* was shifted, as in the former experiments, so as to alter the lengths of the two chambers, but the sum of both lengths remained constant as before.

In the following Tables the three columns bracketed under the head of “Deflection,” contain the arcs through which the needle moved in the three cases mentioned; 1°, when the radiation from the gas in the first chamber passed through the empty second chamber; 2°, when the radiation from the first chamber passed through the occupied second chamber; and 3°, when the radiation proceeded from the second chamber.

*Dynamic Radiation of Gases.*

TABLE XXXIV.—Carbonic Oxide.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Gas in 2nd Chamber.	By 2nd Chamber.
2·8	46·6	1·0	0·0	28·0
15·4	34·0	3·8	2·1	24·4
36·3	13·1	13·7	6·3	16·6

TABLE XXXV.—Carbonic Acid.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Gas in 2nd Chamber.	By 2nd Chamber.
2·8	46·6	1·0	0·0	33·6
15·4	34·0	3·7	1·25	23·3
36·3	13·1	16·8	6·6	17·5

TABLE XXXVI.—Nitrous Oxide.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Gas in 2nd Chamber.	By 2nd Chamber.
2·8	46·6	1·0	0·2	44·5
15·4	34·0	4·3	1·2	31·7
36·3	13·1	19·5	6·2	22·0

TABLE XXXVII.—Olefiant Gas.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Gas in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	11·9	1·0	68·0
23·8	25·6	22·8	3·0	
36·3	13·1	59·0	10·4	65·0

The gases, it will be observed, exhibit a gradually increasing power of dynamic radiation from carbonic oxide up to olefiant gas. This is most clearly illustrated by reference to the results obtained in the respective cases with the first length of the second chamber. They are as follows:—

Carbonic oxide . . . . .	28.0
Carbonic acid . . . . .	33.6
Nitrous oxide . . . . .	44.5
Olefiant gas . . . . .	68.0

Its proximity to the pile, and the fact of its having to cross but one plate of salt, makes the action of the second chamber much greater than that of the first.

Each of the Tables exhibits the fact that as the length of the chamber increases the dynamic radiation of the gas contained in it increases, and as the length diminishes the radiation diminishes. We also see how powerfully the gas in the second chamber acts upon the radiation from the first. With carbonic oxide, the presence of the gas in the second chamber reduces the deflection from  $13^{\circ}.7$  to  $6^{\circ}.3$ ; with carbonic acid it is reduced from  $16.8$  to  $6.6$ ; with nitrous oxide it is reduced from  $19.5$  to  $6.2$ . Now this residual deflection,  $6^{\circ}.2$ , is not entirely due to the transparency of the gas, to heat emitted *by the gas*. No matter how well polished the experimental tube may be, there is always a certain radiation from its interior surface when the gas enters it. With perfectly dry air this radiation amounts to 8 or 9 degrees. Thus the radiation is composite, in part emanating from the molecules in the first chamber, and in part emanating from the surface of the tube. To these latter, the gas in the second chamber would be much more permeable than to the former; and to these latter, I believe, the residual deflection of 6 degrees, or thereabouts, is mainly due. That this number turns up so often, although the radiations from the various gases differ considerably, is in harmony with the supposition just made. In the case of carbonic oxide, for example, the deflection is reduced from  $13^{\circ}.7$  to  $6^{\circ}.3$ , while in the case of nitrous oxide it is reduced from  $19.5$  to  $6.2$ ; in the case of olefiant gas it is reduced from  $59^{\circ}$  to  $10^{\circ}.4$ , while in other experiments (not here recorded) the deflection by olefiant gas was reduced from  $44^{\circ}$  to  $6^{\circ}$ .

As may be expected, this radiation from the interior surface augments with the tarnish of the surface, but the extent to which it may be increased is hardly sufficiently known. Indeed the gravest errors are possible in experiments of this nature if the influence of the interior be overlooked or misunderstood. An experiment or two will illustrate this more forcibly than any words of mine.

A brass tube 3 feet long, and very slightly tarnished within, was used for dynamic radiation. Dry air on entering the tube produced a deflection of 12 degrees. The tube was then polished within, and the experiment repeated; the action of dry air was instantly reduced to  $7.5$  degrees.

The rock-salt plate at the end of the tube was then removed, and a lining of black paper 2 feet long was introduced within it. The tube was again closed, and the experiment of allowing dry air to enter it repeated. The deflections observed in three successive experiments were

$80^{\circ}$ ,           $81^{\circ}$ ,           $80^{\circ}$ .

This result might be obtained as long as the lining continued within the tube.

The plate of rock-salt was again removed, and the length of the lining was reduced to a foot; the dynamic radiation on the entrance of dry air in three successive experiments gave the deflections

76°,            74°,            75°.

The plate was again removed and the lining reduced to 3 inches; the deflections obtained in two successive experiments were

66°,            65°.

Finally, the lining was reduced to a ring only  $1\frac{1}{2}$  inch in width; the dynamic radiation from this small surface gave in two successive trials the deflections

56°,            56°·5.

The lining was then entirely removed, and the deflection instantly fell to  
7°·5.

A coating of lampblack within the tube produced the same effect as the paper lining; common writing-paper was almost equally effective; a coating of varnish also produced large deflections, and the mere oxidation of the interior surface of the tube is also very effective.

In the above experiments the lining was first heated, and it then radiated its heat through a thick plate of rock-salt against the pile. The effect of the heat was enfeebled by distance, by reflexion from the surfaces of the salt, and by partial absorption. Still we see that the radiation thus weakened was competent to drive the needle almost through the quadrant of a circle. If instead of being thus separated from the lining *the face of the pile itself* had formed part of the interior surface of the tube, receiving there the direct impact of the particles of air, of course the deflections would be far greater than the highest of those above recorded. Indeed I do not doubt my ability to cause the needle of my galvanometer to whirl, by the dynamic heating of the surface of my pile, through an arc of 1000 degrees. Assuredly an arrangement subject to disturbances of this character cannot be suitable in experiments in which the greatest delicacy is necessary.

Experiments on dynamic radiation, similar to those executed with gases, were made with vapours. The tube was divided into two compartments as before. Both compartments being exhausted, vapour was permitted to enter the first chamber. Dry air was afterwards permitted to enter the same chamber; the air was heated, it warmed the vapour, and the vapour radiated its heat against the pile. The heat passed in the first experiment through a vacuous second chamber, and in the second experiment through the same chamber when it contained 0·5 of an inch of the same vapour as that from which the rays issued. A third experiment was made to determine the dynamic radiation from the second chamber. The following Tables contain the results:—

*Dynamic Radiation of Vapours.*

TABLE XXXVIII.—Bisulphide of Carbon, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	2·4	1·6	14·2
36·3	13·1	9·75	5·5	9·0

TABLE XXXIX.—Benzol, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	3·0	1·1	34·0
36·3	13·1	21·6	11·9	15·1

TABLE XL.—Iodide of Ethyl, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	3·4	2·7	38·8
36·3	13·1	25·4	13·8	19·0

TABLE XLI.—Chloroform, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	4·5	2·1	41·0
36·3	13·1	22·3	10·0	19·0

TABLE XLII.—Alcohol, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	4·9	2·0	53·8
36·3	13·1	33·8	16·9	34·9

TABLE XLIII.—Alcohol, 0·1 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	2·0	1·3	35·7
36·3	13·1	21·8	16·2	11·5

TABLE XLIV.—Boracic Ether, 0·1 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	6·3	2·1	61·0
36·3	13·1	29·1	15·7	31·6

TABLE XLV.—Formic Ether, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	6·3	2·5	68·0
36·3	13·1	46·0	23·8	41·0

TABLE XLVI.—Sulphuric Ether, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	5·6	2·5	68·0
36·3	13·1	45·3	22·4	36·5

TABLE XLVII.—Acetic Ether, 0·5 inch.

Length.		Deflection.		
1st Chamber.	2nd Chamber.	By 1st Chamber. 2nd Chamber empty.	By 1st Chamber. Vapour in 2nd Chamber.	By 2nd Chamber.
15·4	34·0	5·7	1·0	73·9
36·3	13·1	49·1	22·0	41·0

Collecting the radiations from the second chamber for the lengths 34 inches and 13·1 inches together in a single Table, we see at a glance how the radiation is affected by varying the length.

TABLE XLVIII.

Dynamic radiation of various vapours at 0·5 inch pressure and a common thickness of		
	34 inches.	13·1 inches.
Bisulphide of carbon . . . . .	14·2	9·0
Benzol . . . . .	34·0	15·1
Iodide of ethyl . . . . .	38·8	19·0
Chloroform . . . . .	41·0	19·0
Alcohol . . . . .	53·8	34·9
Sulphuric ether . . . . .	68·0	36·5
Formic ether . . . . .	68·0	41·0
Acetic ether . . . . .	73·9	41·0
At a pressure of 0·1 of an inch.		
Alcohol . . . . .	35·7	11·5
Boracic ether . . . . .	61·0	31·6

The extraordinary energy of boracic ether as a radiant may be inferred from the last experiment. Although attenuated to  $\frac{1}{300}$ th of an atmosphere, its thinly scattered molecules are able to urge the needle through an arc of 61 degrees, and this merely by the warmth generated on the entrance of dry air into a vacuum.

Arranging the gases in the same manner, we have the following results:—

TABLE XLIX.

Dynamic radiation of gases at 1 at. pressure and a common thickness of		
	34 inches.	13·1 inches.
Carbonic oxide . . . . .	24·4	16·6
Carbonic acid . . . . .	23·3	17·5
Nitrous oxide . . . . .	31·7	22·0
Olefiant gas . . . . .	68·0	65·0

The influence of tenuity which renders the vapour at 0·5 of an inch a more open screen than the gas at 30 inches is here exhibited. In the case of the vapour, a greater length is available for radiation than in the case of the gas, because the radiation from the hinder portion of the column of vapour is less interfered with by the molecules in front of it than is the case with the gas. By shortening the column we therefore do more injury to the vapour than to the gas; by lengthening it we promote the radiation from the vapour more than that from the gas. Thus while a shortening of the gaseous



column from 34 inches to 13.1 causes a fall in the case of nitrous oxide only from  $23^{\circ}3$  to  $17^{\circ}5$ , the same amount of shortening causes benzol vapour to fall from  $34^{\circ}$  to  $15^{\circ}1$ —a much greater diminution. So also as regards olefiant gas, a shortening of the radiating column from 34 inches to 13.1 inches causes a fall in the deflection only from  $68^{\circ}$  to  $65^{\circ}$ ; the same diminution produces with sulphuric ether a fall from  $68^{\circ}$  to  $36^{\circ}5$ ; and with acetic ether from  $73^{\circ}9$  to  $41^{\circ}$ . In the long column acetic ether vapour beats olefiant gas, but in the short column the gas beats the vapour.

One of the earliest series of experiments of this nature which were executed last autumn, though not free from irregularities, is nevertheless worth recording. The experiments were made with a brass tube, slightly tarnished within, the tube being 49.4 inches long, and divided into two equal compartments, each 24.7 inches in length, by a partition of rock-salt placed at the centre of the tube.

TABLE L.—Dynamic radiation of Vapours.

	Deflection.		
	By 1st Chamber. 2nd Cham. empty.	By 1st Chamber. Vapour in 2nd Cham.	By 2nd Chamber.
Bisulphide of carbon . . . . .	8.2	5.8	21.2
Benzol . . . . .	20.0	12.4	45.9
Chloroform . . . . .	24.3	10.9	55.2
Iodide of ethyl . . . . .	27.5	14.7	55.3
Alcohol . . . . .	42.7	22.3	69.0
Sulphuric ether . . . . .	46.3	21.7	80.5
Formic ether . . . . .	47.5	19.8	79.5
Propionate of ethyl . . . . .	49.8	25.0	82.3
Acetic ether . . . . .	53.3	30.0	82.1

To ascertain whether the absorption by the vapours bears any significant relation to the absorption by the liquids from which these vapours were derived, the transmission of radiant heat through those liquids was examined. The open flame of an oil-lamp was used, and the liquids were enclosed in rock-salt cells. Thus the total radiation from the lamp, with the exception of the minute fraction absorbed by the rock-salt, was brought to bear upon the liquid.

In the following Table the liquids are arranged in the order of their powers of transmission.

TABLE LI.

Name of liquid.	Transmission in hundredths of the radiation.
Bisulphide of carbon . . . . .	83
„ „ saturated with sulphur . . .	82
„ „ „ with iodine . . . .	81
Bromine . . . . .	77
Chloroform . . . . .	73
Iodide of methyl . . . . .	69
Benzole . . . . .	60
Iodide of ethyl . . . . .	57
Amylene . . . . .	50
Sulphuric ether . . . . .	41
Acetic ether . . . . .	34
Formic ether . . . . .	33
Alcohol . . . . .	30
Water saturated with rock-salt . . . . .	26

These results are but approximate, but they are not very far from the truth; and it is impossible to regard them without feeling how purely the act of absorption is a *molecular* act, and that when a liquid is a powerful absorber the vapour of that liquid is sure also to be a powerful absorber.

To experiment with water, it was necessary to saturate it with the salt of which the cell was formed, but the absorptive energy is due solely to the water. We might infer from this alone, were no experiments made on the aqueous vapour of the atmosphere, that that vapour must exert a powerful action upon terrestrial radiation. In fact, in all the statements that I have hitherto made I have underrated its action.

The deportment of the elements sulphur and iodine, dissolved in bisulphide of carbon, is in striking harmony with all that we have hitherto discovered regarding the action of elementary bodies. The saturation of the bisulphide by sulphur scarcely affects the transmission, while a quantity of iodine sufficient to convert the liquid from one of perfect transparency to one of almost perfect opacity to light, produces a diminution of only two per cent. of the radiation. This shows that the heat really used in these experiments consists almost wholly of the obscure rays of the lamp. It is worth remarking that the obscure rays of a luminous source have a much greater power of penetration in the case of the liquids here examined than the rays from an obscure source, however close to incandescence. The deportment of bromine is also very instructive. The liquid is very dense, and so opaque as to cut off the luminous rays of the lamps, till it transmits 77 per cent. of the total radiation. It stands in point of diathermancy above every compound liquid in the list except bisulphide of carbon. This latter substance is the rock-salt of liquids.

Before a strict comparison can be made between vapours and liquids, they must be examined by heat of the same quality, and I have already made arrangements with which I hope to obtain more complete and accurate results than those above recorded.